South Carolina
Department of Natural Resources
Marine Resources Research Institute

The Tidal Creek Project

Summary Report

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Submitted by:

Dr. A. Frederick Holland, George H.M. Riekerk,
Scott B. Lerberg, Lynn E. Zimmerman, Denise M. Sanger
Marine Resources Division
Marine Resources Research Institute

and

Dr. Geoffrey I. Scott, Dr. Michael H. Fulton,
Brian C. Thompson, James W. Daugomah, John C. DeVane,
Kevin M. Beck, Aaron R. Diaz
U.S. National Marine Fisheries Science Center
Southeast Fisheries Science Center

Submitted to:

J. Heyward Robinson
Project Director
Charleston Harbor Project

Executive Summary & Conclusions

Identification of the Problem

Meandering shallow tidal creeks and salt marshes are dominant features of Southeastern estuaries and provide nursery habitat for many species of fish, crabs, and shrimp. Shallow tidal creeks are also conduits through which many pollutants enter estuaries with creek sediments serving as repositories for potentially toxic chemicals.

Resource management and regulatory agencies responsible for protecting estuarine environments do not know if the policies and programs they have implemented adequately protect shallow tidal creeks and the important ecological and environmental services they provide. These agencies also do not have the knowledge needed to restore degraded creeks.

Scientific Information Needed to Solve the Problem

In 1994, the South Carolina Marine Resources Research Institute initiated a study, called the Tidal Creek Project (TCP), to develop the information needed to ensure tidal creeks nursery habitats were adequately protected. This study was funded jointly by the Charleston Harbor Project and the Marine Recreational Fishery Advisory Board. Objectives of the TCP were to: (1) characterize and define the ecological values and services of tidal creek systems, (2) identify pollution threats to the ecological values and services of tidal creeks resulting from human development, and (3) develop environmental quality criteria for sustaining tidal creek nursery functions. The National Marine Fisheries Service (NMFS), Charleston Laboratory was a co-participant in the TCP. NMFS provided analytical chemistry and toxicology support and conducted population studies of grass shrimp, an important resident forage species, in tidal creeks.

The general approach used by the TCP was to sample tidal creeks draining relatively pristine, undeveloped watersheds and creeks draining highly developed watersheds. Creeks were selected to represent the major types of watershed development that existed in the Charleston Harbor Ecosystem (CHE). Then, creeks of similar sizes and physical characteristics were contrasted to define differences in environmental and ecological characteristics that were associated with various types of human development and land cover. This approach is generally referred to as the comparative assessment approach.

In 1994, the TCP sampled 24 tidal creeks during summer when temperature, salinity, and dissolved oxygen levels in creeks approached annual extreme values and were very stressful to biota. A range of pollution exposure and ecological response measurements were made in each creek. Half of the creeks drained urban, suburban, industrial, and/or agricultural (developed) watersheds, and half drained salt marsh and forested (reference) watersheds. Selected creeks were re-sampled in 1995 to measure year-to-year variability. In addition, reference and developed creeks throughout the state were sampled in 1995 to determine if information about tidal creek ecosystems of the CHE had state-wide applicability. The tidal creeks studied by the TCP included representatives of the major land cover types and sizes of creeks that comprise the CHE. The sample population of creeks also included representatives from the major salinity zones and sediment types that exist in the CHE.

Since its inception the TCP has collected and processed environmental and ecological data as well as information about watershed characteristics for 30 tidal creeks. Water quality data records for selected creeks span many months and include data from several years. Only about 60% of the samples collected by the TCP have been processed. The data in this Interim Report describes project status and discusses the data collected from 20 creeks, 10 with undeveloped (reference) watersheds and 10 with developed watersheds.

The remaining samples and associated data will be processed and analyzed in 1996 and used to validate and refine the findings of this Interim Report including assessing their state-wide applicability. A Final Report will then be prepared that: (1) recommends environmental quality criteria for providing tidal creek nurseries the degree of environmental protection needed to maintain them as the human population of South Carolina grows; and (2) develops strategies for monitoring the environmental status and trends of tidal creeks over the long term. The Final Report is scheduled to be completed in late 1996.

The accuracy, precision, representativeness, completeness, and comparability of the information produced by the TCP were evaluated through a formal Quality Assurance (QA) Program. This program was designed to ensure the information produced by the TCP was adequate for addressing study objectives and developing environmental policy. A computerized relational data base was also established for the TCP to facilitate efficient storage, retrieval, and analysis of the data produced. This data base also makes the data produced by the TCP readily accessible to other researchers as well as to regulatory and resource management agencies. A copy of the TCP data base will be provided to state and federal agencies upon request.

Summary of Technical Findings

Salinity is a major factor controlling the distribution and abundance of living resources in estuaries. Salinity fluctuated over greater ranges and was generally more variable in developed creeks than in reference creeks. The more variable and extreme salinities in developed creeks may be related to the "flashier" runoff associated with the increased amount of impervious surface in their watersheds (e.g., roofs, roads, parking lots). Creeks that were dominated by salt marshs had the least variable salinity distributions.

Physical sediment characteristics are also important environmental factors controlling the distribution of the living resources in estuaries. Sediments in developed creeks were composed of more sand and had larger site-to-site variation in physical characteristics than reference creeks. The greater sand content and more variable sediment characteristics in developed creeks were probably associated with erosion and deposition of surface soils from tidal creek watersheds. The dominant soil types in these watersheds have a high sand content. Information on soils of the watersheds needs to be included in the TCP data base.

Dissolved oxygen concentration (DO) is a fundamental requirement for maintaining balanced, indigenous populations of fish, shellfish, and other aquatic biota in estuaries. Pollution related decreases in DO is generally considered to be the greatest threat to the environmental quality of estuaries. DO in tidal creeks fluctuated with time of day and stage of the tide. Point-in-time measurements of tidal creek DO does not adequately represent the exposure of living resources to stressful low DO events. The lowest and most stressful DO to living aquatic resources occurred during early morning and night-time low tides. DO in both reference and developed creeks frequently did not meet state water quality standards (4 mg/l). Living resources inhabitating developed creeks were exposed to stressful low DO events more frequently than living resources inhabitating reference creeks.

Tidal creek sediments are repositories for pollutants. Trace metal concentrations in sediments of the upper reaches of industrialized creeks were enriched with trace metals to levels known to adversely affect living resources. Sediment bioassays also indicate that sediments in the upper reaches of developed creeks, particularly industralized creeks, were potentially toxic to living resources. Sediment trace metal concentrations in reference creeks rarely exceeded values known to cause biological harm, and sediment bioassays from reference creeks did not suggest exposure to these sediments would result in acute or chronic impacts on living resources.

Samples of organic chemicals in sediments taken by the TCP included measurement of polycyclic aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs), and pesticides. These samples have only been partially processed and evaluated. The general distribution of organic chemicals, however, appears to be similar to that for trace metals. The class of organic chemicals that appeared to represent the greatest threat to tidal creek nurseries is the PAHs. Most of these are the result of the combustion of hydrocarbon-based fuels. A detailed analysis of the distribution of organic chemicals in creek sediments will be included in the Final Report to be prepared in 1996.

Biota (worms, crustaceans, clams, snails) that live in creek sediments (called benthic organisms) are an important food item for fish, shrimp, and crabs which use tidal creeks as nurseries. Because these benthic organisms have limited mobility, they can not avoid adverse environmental conditions and pollutant exposure associated with human development of tidal creek watersheds. Differences in the abundance and kinds of benthic organisms between reference and developed creeks is, therefore, potentially a sensitive indicator of the suitability of environmental conditions in creeks for living resources.

Assemblages of benthic organisms inhabitating creek sediments were dominated by oligochaetes (aquatic earthworms) and polychaetes (segmented marine worms). Highest benthic abundances occurred in the upper reaches of creeks which is the location of greatest potential risk to chemical contamination. Most of the taxa that composed the benthic assemblages of tidal creeks are known for their broad environmental tolerances.

The kind of benthic prey available to fish, crabs, and shrimp using tidal creeks as nurseries varied with salinity and sediment characteristics. Polychaetes were the dominant benthic fauna in high salinity creeks and oligochaetes were the dominant benthic fauna in low salinity creeks. Polychaetes were also the dominant benthic biota in sand, and oligochaetes were the dominant benthic biota in mud.

Human activities associated with watershed development did not adversely affect the biodiversity of benthic organisms in creeks. The number of different kinds of taxa in developed and reference creeks were similar. On a regional scale, CHE-wide phenomena (e.g., long-term salinity distributions, estuary-wide water quality degradation) are more important in controlling biodiversity of estuarine benthos than are local processes.

Variation in benthic organisms due to natural factors (salinity, sediment characteristics, and location within tidal creeks) was large. After accounting for these natural sources of variation, both increases and decreases in the abundance of benthic organisms were found in the upper-most reaches of tidal creeks. These differences could be attributed to human development of the watershed. Reference and developed creeks had similar kinds and abundance of benthic organisms in their lower reaches. These data indicate that watershed development did not substantially alter the amount of benthic prey (i.e.,food) that was available to fish and shrimp in tidal creeks. They also suggest that development effects on the kinds and abundances of benthic organisms were limited to the upper reaches of tidal creeks.

The TCP also conducted a colonization/recruitment experiment in summer 1994 to assess the rate at which benthic organisms colonized creeks sediments and to evaluate the potential of this technology as a monitoring and assessment tool. Benthic organisms were selected for this experiment because they have a broad variety of reproductive modes and life history strategies including free-living planktonic and nurtured/brooded early life stages. Many benthic biota complete the greatest part of their life cycle over time periods as short as several months and most of the species that are abundant in tidal creeks reproduce throughout much of the year. Some of the abundant benthic biota in tidal creeks even appear to complete their life cycle within specific tidal creeks. Because of the above characteristics, an evaluation of difference in benthic recruitment and colonization processes between reference and developed creeks should provide an indication of the effects of watershed development on living resource recruitment processes at the scale of tidal creeks.

A similar evaluation of recruitment processes based on mobile organisms, like fish or shrimp that only reproduce once per year and only complete a portion of their life cycle in creeks, would be much more difficult to interpret, take much longer to complete, and cost substantially more. The major questions the recruitment experiment addressed were: (1) how do benthic organisms maintain high population densities in creeks during summer when predation by fish, shrimp, and crabs is great; and (2) is altered recruitment processes an important mechanism by which human alterations to watersheds can affect living resources in tidal creeks.

Results of the colonization and recruitment experiments demonstrated that benthic resources maintained high population levels in creeks by continually recruiting to bottom sediments over the summer. Salinity, sediment characteristics, location within creeks, and predation by fish and shrimp had large influences on recruitment success. Predation was a particularly important factor affecting recruitment success. After accounting for variation in recruitment due to the above natural factors, human alterations of tidal creek watersheds were found to adversely affect the abundance of only one numerically abundant species. Otherwise, recruitment processes for reference and developed creeks were similar. Results of the benthic colonization experiment suggest that the effects of watershed development on recruitment processes were subtle and not likely to substantially affect the amount of prey available to living resources using tidal creeks as nursery habitat.

The grass shrimp population study showed that larval grass shrimp recruited equally to reference and developed creeks. The survival of new recruits was, however, much greater in reference creeks. As a result fewer adult grass shrimp were found in developed creeks. These data along with the benthic colonization/recruitment experiment suggest that human development of tidal creek watershed impacts survival of living resources more than their recruitment processes.

Forage species for recreationally and commercially important fish, crabs, and birds, particularly mummichogs and grass shrimp, were the most abundant fish and crustaceans found in tidal creeks during summer. These biota are tolerant to broad fluctuations in salinity and DO. Penaeid shrimp were the overwhelmingly dominant living resources using tidal creeks as a nursery. Spot was the most abundant fish that used tidal creeks as a nursery. Highest population levels of fish and shrimp occurred in the upper reaches of tidal creeks which were at the greatest risk to chemical contamination. Early life stages of recreationally and commercially important fish and crustaceans were infrequently collected from developed creeks and were most consistently found in reference creeks where the dominant land cover was salt marsh. Statistical analyses to assess the effects of environmental alterations associated with watershed development on juvenile fish and crustaceans occurring in tidal creeks will be completed in summer 1996 and presented in the Final Report.

Fish and crustaceans in size ranges sought by fishermen were rarely collected from tidal creeks. These biota may not be able to tolerate the low DO conditions or other environmental alterations that occur in tidal creeks during summer. Larger fish and crabs (late juveniles and sub-adults) were much more abundant in shallow water adjacent to tidal creeks where low DO events are less frequently encountered. Statistical analyses to assess the effects of environmental alterations associated with watershed development on large fish and crustaceans will be completed in summer 1996 and presented in the Final Report.

Conclusions and Recommendations

The major environmental threats to tidal creek nurseries of the CHE from human development of their watersheds were: (1) alterations to salinity distributions; (2) alteration to the type of sediments composing creek bottoms; (3) alteration of DO dynamics including increased exposure of living resouces to stressful low DO conditions; and (4) exposure to chemical contaminants in ranges that may cause biological harm. These are the same environmental threats that regulatory agencies have identified as representing the greatest risk to the Nation's major estuaries including Chesapeake Bay, Long Island Sound, Tampa Bay, Galveston Bay, and San Francisco Bay.

Human related alterations to salinity distributions of tidal creeks of the CHE included increased variation, more frequent extreme fluctuations, and wider ranges. The living resources inhabitating tidal creeks of the CHE have broad tolerances to salinity fluctuations, and specific assemblages (i.e., kinds and abundances) of biota were associated with the various salinity zones/classes that occur. The alterations to salinity distributions that were found by this study and attributed to human development of watersheds may have contributed to increases and/or decreases in the abundance of selected biota in tidal creeks. A few species may have been excluded from specific creeks by salinity alterations; however, this was probably a rare event.

The major alteration to the sediment characteristics of tidal creeks associated with human development of watersheds of the CHE was increases in the amount of sand composing creek bottoms. The living resources inhabitating the tidal creeks of CHE have specific sediment preferences, and different assemblages (i.e., kinds and abundances) of resources were characteristic of each of the major sediment types that occurred in tidal creeks. Increases in the sand content of creek bottom sediments may have resulted in increases and/or decreases in the abundance of selected biota. For example, juvenile Penaeid shrimp maintain highest abundances in creeks with soft muddy sediments and would be expected to have lower abundances in creeks with predominantly sand bottoms. It is unlikely, however, that changes in sediment characteristics eliminated any living resource from specific creeks.

Information on the salinity and sediment type tolerances and preferences of the abundant living resources inhabitating tidal creeks and other critical habitats needs to be compiled and synthesized. This information would assist resource management and regulatory agency staff in defining the living resources that would be expected for specific environmental conditions and facilitate assessment of the effects and impacts of proposed changes.

The alterations to DO dynamics that were found to be associated with human development of tidal creek watersheds are particularly problematic. The vast majority of the creeks studied failed to meet state DO standards. Developed creeks, however, most frequently violated standards and appeared to have the greatest exposure to low DO conditions.

The scientific basis for existing DO standards is that increases in the duration and severity of exposure to low DO will result in adverse ecological changes ranging from direct mortality (e.g., fish kills) to shifts in the kinds and abundances of organisms that are abundant (e.g., pollutant tolerant biota generally dominate low DO environments). Moderately low DO, however, may be an inviable barrier that protects the low DO tolerant juvenile fish and shrimp using tidal creeks as nurseries from their predators. This phenomena may be especially important during low tide when juvenile organisms are concentrated in shallow water and the most vulnerable to predation. We currently do not have the scientific information needed to understand or assess the ecological value of moderately low DO conditions in tidal creeks. The research needed to determine if moderate DO is a barrier to predators needs to be tested. This testing program should include both *in situ* tethering experiments as well as laboratory/mesocosm evaluations of low DO effects on predator-prey interactions.

Factors that contribute to low DO in tidal creeks have not been identified or evaluated. Currently, we do not know if the observed alterations to DO dynamics in developed tidal creeks is associated with increased loading of oxygen consuming material, increased loadings of nutrients (nitrogen and phosphorous) that stimulate excessive growth of primary producers, and/or some other unidentified cause. Until the low DO in tidal creeks can be linked to contributing factors, it is unlikely that it can be efficiently remediated should policies be developed that decide to do so.

Existing DO standards for aquatic environments do not appear to be meaningful for tidal creek habitats. In addition, current regulatory tools (i.e., models) used to allocate DO among major consumers (e.g., dischargers) of Charleston Harbor do not include estimates of the DO needed to preserve and maintain the ecological services provided by tidal creeks and the associated salt marshes. Tidal creeks and the associated salt marshs, however, appear to be a major DO consumer. A DO budget for tidal creeks and the associated salt marshes that defines their relative importance as consumers and identifies the major factors controlling low DO conditions needs to developed. This budget is a critical element for the development of DO standards that protects living resources in tidal creeks as well as sustains their nursery functions. The data collected by, and findings of, the TCP provide a starting point for developing a DO budget for tidal creek habitats.

Although only limited DO measurements have been made from headwaters to the mouth of tidal creeks, low DO conditions appeared to be pervasive throughout the extent of tidal creeks. Living resources in both relatively pristine, reference as well as highly developed creeks were frequently exposed to low DO conditions. The pervasive nature of low DO throughout tidal creeks and its presence in the undeveloped, relatively pristine as well as highly developed creeks probably contributed to the relatively high abundance of "pollution tolerant" biota in tidal creeks (e.g., mummichogs, Tubificid oligochaetes, *Streblospio benedicti*). Exposure to low DO does not explain the difference in biological distributions that were generally confined to the upper-most reaches of tidal creeks.

Observed increases in the amount of toxic chemicals in sediments that were attributed to watershed development were also disconcerting. They represent a persistent long-term threat to living resources as well as humans that consume seafood derived from tidal creek nurseries. Toxic chemicals can also bioaccumulate in resident and transient living resources inhabiting creeks. Increases in tissue levels of toxic chemicals has a broad range of acute and chronic biological effects including reduced growth, declines in reproductive output, compromised resistance to pathogens, and reduced survival. Trophic transfer may also represent a mechanism through which toxic chemicals are transferred from tidal creeks to the CHE and/or man. Most importantly, however, the cost of remediating toxic chemical inputs to tidal creeks or rendering the chemicals that already exist in creek sediments is large.

We assisted the NMFS Seattle Laboratory in collecting information on bioaccumulation of toxic substances by selected resident and transient living resources, including several resident and transient fish species, for selected developed and reference creeks. We plan to include these data into the TCP data base in 1996 or 1997 (i.e., when NMFS releases them). We are also evaluating the bioaccumulation of toxic chemicals by oysters deployed in selected reference and developed creeks. Tolerances of selected crustaceans (grass shrimp and amphipods) that inhabit tidal creeks to a range of chemical contaminant exposures under funding from the U.S. Environmental Protection Agency, Gulf Breeze Environmental Research Laboratory were also evaluated. When these studies are completed, the information they produce will also be incorporated into the TCP data base and summaries of these findings will be made available to state resource management and regulatory agencies.

An important source of some of the toxic substances found in tidal creeks is apparently due to specific current and/or historical industrial operations. Research to better define the sources of the toxic chemicals at localized "hot spots" should be conducted. We plan to use "chemical fingerprinting" to determine the proportion of the PAHs that were derived from combustion of hydrocarbon fuels. In addition, when the chemical data base for tidal creeks has been developed, we recommend that discriminant analysis and other multivariate statistical analyses be conducted to determine if specific chemical signatures can be associated with specific watershed types.

Vegetation buffer strips along creek shorelines, banks, and catchment basins that trap sediments from major terrestrial sources are frequently recommended technologies for reducing inputs of toxic chemicals to tidal creeks. These technologies will not effectively reduce the loading of toxic chemicals to tidal creeks unless they are retrofit to the majority of the parking lots, roadways, streets, and/or buildings that occur in tidal creek watersheds. We recommend that technologies designed to trap sediments and the chemicals they contain in the headwaters of creeks (e.g., porous dams) and treatment in the creek bed with substances that make toxic chemicals unavailable to biota also be evaluated.

Research on the chronic, sublethal effects of chemical contamination to the health of individual organisms in tidal creeks needs to be conducted. The population of tidal creeks identified by this study and the associated data base that has been developed on environmental conditions provide a research platform for designing and conducting this research. Priority research topics include evaluation of the effects of contamination on immune systems, genetic adaptations of resident living resources to continual exposure to high levels of chemical contaminants over generations, trophic transfer of contaminants as a means of export, and *in situ* effects of contaminant exposure on survivorship, growth, and production of valued living resources (e.g., juvenile red drum).

Tidal creeks located in the most perturbed watersheds sampled by the TCP functioned as nurseries for fish, shrimp, and crabs. Perturbed creeks, however, contained less food resources for juvenile fish and shrimp and did not support juveniles of many kinds of recreationally and commercially important fish. These population and community level alterations were generally limited to the upper-most reaches of creeks and mainly appear to be related to increased exposure to chemical contaminants. The amount of oxygen that is available in tidal creeks to support biological resources during critical night-time, low tides was also reduced and influenced ecological characteristics of tidal creeks. The ecological consequences of these subtle, localized alterations in tidal creeks to the CHE are not well understood. We, however, believe they are "early warnings" of more widespread degradation that will occur if the factors that contributed to these problems are not remediated. It is interesting that these are the same symptoms that were identified for Chesapeake Bay in the early to mid 1970s when it became obvious that the living resource populations of the Bay were in declining.

The technical data that has been developed by the TCP provides a basis for designing many of the experiments and research programs that should be conducted for tidal creeks in the future. Researchers from many disciplines (e.g., immunologists, geochemists, ecological modelers) should be encouraged to use these data as a building block for future research programs.

The scientific knowledge about tidal creek habitats resulting from the TCP and other Charleston Harbor Project studies should be summarized in a manner that can be understood by the public and environmental decision makers. This information should also be used to develop monitoring strategies and requirements for tidal creek habitats and include comparisons of tidal creek habitats to other shallow environments.